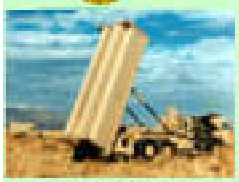
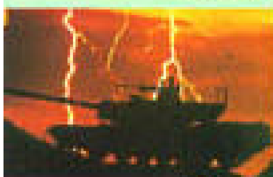
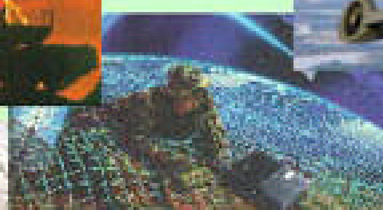


ARMY WEAPON SYSTEMS SURVIVABILITY





March 2000

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U.S. Army Research Laboratory

SLAD

ARMY WEAPON SYSTEMS SURVIVABILITY

FOREWORD

In an address to the 45th Annual Meeting of the Association of the U.S. Army, 12 October 1999, Army Chief of Staff, General Eric K. Shinseki articulated his vision for the Army as soldiers on point for the nation transforming the most respected Army in the world, into a strategically responsive force that is dominant across the full spectrum of operations. His goal is to deliver a combat capable brigade anywhere in the world in 96 hours, a division on the ground in 120 hours, and five divisions in 30 days. General Shinseki envisions providing the agility and the versatility to transition rapidly from one point on that spectrum to another with the least loss of momentum. He has challenged the Army to find and prioritize solutions that optimize smaller, lighter, more lethal, yet more reliable, fuel-efficient, and more survivable options. To that end, the Army will seek the best combination of technologies that will provide survivability through low observable, ballistic protection, long-range acquisition, deep targeting, early attack, and first round kill at smaller caliber solutions.

The Survivability/Lethality Analysis Directorate (SLAD) of the U.S. Army Research Laboratory (ARL) is an Army focal point for technical advice and consultation on vulnerability and lethality analysis and integrated technical analysis of the survivability of all Army systems. This document, developed by SLAD, contains a tutorial on survivability considerations to assist in making the hard decisions on system selections supporting the Army vision. It also contains information on SLAD that will assist Army combat developers and decision makers obtain technical assistance in resolving survivability and lethality issues.

Comments and/or questions regarding this document should be directed to the Survivability/ Lethality Analysis Directorate, U. S. Army Research Laboratory, ATTN: Mr. Connie Hopper, White Sands Missile Range (WSMR) 88002-5513. Telephone: DSN 258-7952 or Commercial (505) 678-7952.

SECTION I
SYSTEM SURVIVABILITY AS PART OF THE ARMY VISION

A DIFFERENT KIND OF ARMY IN A DIFFERENT AND DANGEROUS WORLD

The world environment has changed fundamentally from the former bipolar environment of the Cold War. “The world remains a dangerous place full of authoritarian regimes and criminal interests whose combined influence extend the envelope of human suffering by creating haves and have-nots. They foster an environment for extremism and the drive to acquire asymmetric capabilities and weapons of mass destruction. They also fuel an irrepressible human demand for freedom and a greater sharing of the better life. The threats to peace and stability are numerous, complex, oftentimes linked, and sometimes aggravated by natural disaster. The spectrum of likely operations describes a need for land forces in joint, combined, and multinational formations for a variety of missions extending from humanitarian assistance and disaster relief to peacekeeping and peacemaking to major theater wars, including conflicts involving the potential use of weapons of mass destruction. The Army will be responsive and dominant at every point on that spectrum. We will provide to the Nation an array of deployable, agile, versatile, lethal, survivable, and sustainable formations, which are affordable and capable of reversing the conditions of human suffering rapidly and resolving conflicts decisively. The Army's deployment is the surest sign of America's commitment to accomplishing any mission that occurs on land."[1]

Today, and in the foreseeable future, the spectrum of likely military operations ranges from sustaining and support operations (SASO) to small-scale contingencies (SSC) to major theater war (MTW) as shown in Figure I-1. The Army plans to develop the capability to be strategically responsive and capable in meeting requirements for small-scale contingencies without compromising our MTW capability. The objective force is a rapidly deployable combat brigade that:

-in small-scale contingencies, is capable of determining the outcome;

-in stability and support operations, is the guarantor combat force, and

-in MTW, can fight as part of the Division.

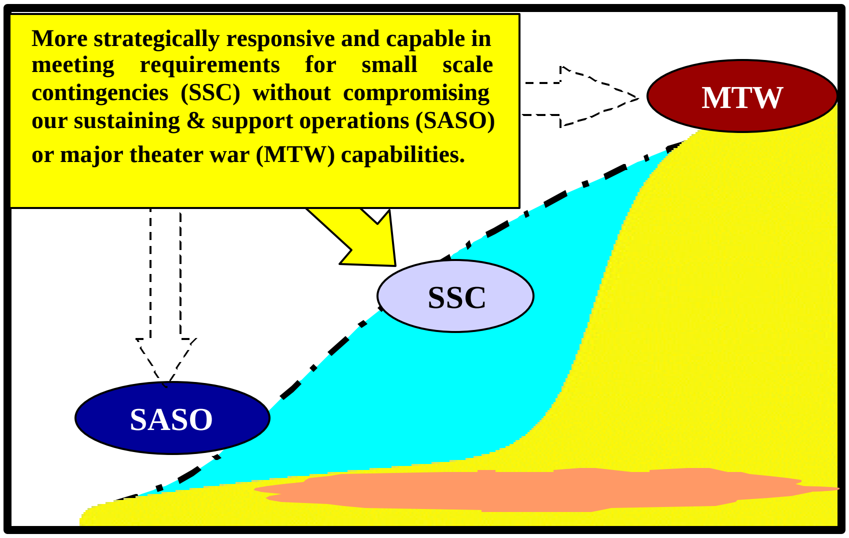

Figure I-1. Full Spectrum Force - Strategically Responsive and Dominant.

As witnessed in Somalia, some missions may begin benignly, but can suddenly become highly dangerous for our soldiers due to inherent uncertainties and/or restrictive rules of engagement. In some scenarios, our soldiers may not have the authority or capability to fire first.

[1] **Army Vision Statement, 12 October 1999.**

Their lives may depend solely on the level of protection our technology provides. It does not matter what the current intentions of the countries are. If we have learned any lesson from history, it is our inability to accurately predict the current or future intentions of most nations. Any country that might become our adversary next year or 10 years from now can acquire world-class, highly effective weapons on the global market. The U.S. Army must possess the ability to deploy capable and survivable military forces that can accomplish the broad variety of tasks they may be assigned. System survivability must encompass threats that run the gamut from the crude to the sophisticated—from homemade booby traps to remotely launched "smart" missiles.

Over the next decade, there is every indication that weapons and weapons technology will proliferate at an even greater pace. During the Cold War, both the North Atlantic Treaty Organization (NATO) and the Warsaw Pact made some efforts to keep sensitive weapons technologies from falling into the hands of the other side or third parties. With the reduction of tensions between NATO and Eastern Europe countries, and the dissolution of the Warsaw Pact, less restricted and more vigorous international arms sales may permit countries with regional aspirations to acquire very sophisticated, highly lethal weapons. The effectiveness of sophisticated American weapons during the Gulf War is a lesson not lost on the countries of the world. Among the capabilities they hope to possess are smart weapons and munitions that markedly improve the weapons' accuracy, as well as allow them to be fired from greater distances. Another emerging threat will be improved reconnaissance and surveillance. These countries understand that one of the keys to increased lethality in modern warfare is early target acquisition. Also, the great advantage U.S. forces currently possess during periods of limited visibility may be challenged. Forward-looking infrared (FLIR) technology of increasing sophistication is available on the world's markets. Other significant threats are the possible employment of weapons of mass destruction, information warfare, terrorism, or other asymmetric means against our forces. We can depend on our future adversaries to use their most effective weapons against our most vulnerable points.

The survivability and lethality of materiel and soldiers is a critical part of mission accomplishment, whether the mission is peacekeeping or war. Department of Defense (DOD) Regulation 5000.2, "Mandatory Procedures for Major Defense Acquisition Programs (MDAPs) and Major Automated Information System (MAIS) Acquisition Programs," and Army Regulation 70-75 "Survivability of Army Personnel and Materiel" require that survivability of Army systems be addressed throughout the acquisition process. These laws and regulations notwithstanding, public expectations, heightened by the blow-by-blow media coverage during Operation Desert Storm, and the Army's own expectations for decisive battles, low casualties, and low collateral damage have brought increased emphasis on how the Army addresses system survivability, lethality, and vulnerability.

THE SURVIVABILITY CHALLENGE

"We will derive the technology that provides maximum protection to our forces at the individual soldier level whether that soldier is dismounted or mounted."[1] The goals of increased agility and deployability will require technological solutions that optimize system size, weight, lethality, and survivability. Survivability solutions will require the best combination of technologies that will provide low observable, ballistic protection, long-range acquisition, deep targeting, early attack, and first round kill at smaller caliber solutions. As an example, the use of anything to increase system survivability may be constrained in terms of adding to system weight. This is particularly true for ballistic armor, but even more advanced approaches to protection, such as reactive armor, active protection systems, or even electronic protection measures, may impose some additional weight requirements on the system design. These can be both direct and indirect (e.g., increased electrical power requirements for defensive measures could mean bigger, heavier power-generation and/or storage subsystems). Increased armor could require heavier automotive and suspension systems).

By itself, the necessity to minimize friendly casualties and preserve mission essential equipment in the face of increased threats and hostile environments is a difficult challenge. But to do so, while reducing the weight of system designs and in a less than robust funding environment, is especially challenging.

WHAT DOES IT TAKE TO BE SURVIVABLE?

There are many things the Army does that contribute to the survivability of its forces, weapons systems, equipment, and soldiers. Almost all efforts done well in the areas of doctrine, training, leader development, organization, materiel, and soldiers (DTLOMS) will have an impact on survivability. The soundness of our doctrine, realism of our training, competence of our leaders, the equipage and mix of our forces, and the intelligence and toughness of our soldiers all contribute to minimizing friendly losses. In a somewhat more specific sense, the following capabilities all affect the survivability of U.S. forces, systems, equipment, and soldiers: strategy; mobility; tactics, techniques, and procedures (TTP); information dominance and situational awareness; operating inside the enemy's decision loop; concealment and deception; dispersion of forces; and equipment reconstitution. And, of course, damaging and destroying enemy forces before they can strike, particularly without revealing friendly forces' locations and dispositions, have a significant effect on the survivability of friendly forces.

Notwithstanding the valuable contributions of all these elements, having inherently survivable weapons systems, equipment, and soldiers is still very important to the survivability of U.S. forces. The focus of this document is the issue of survivability at the system level. Opportunities to ensure the adequacy of the survivability of new weapons systems and enhance the survivability of existing ones will occur as the Army continues to modernize.

SURVIVABILITY DEFINITIONS

Survivability is defined as "The capability of a system and crew to avoid or withstand a man-made hostile environment without suffering an abortive impairment of its ability to accomplish its designated mission."[2] The roles and responsibilities for soldier survivability are defined in Army regulations. These regulations define soldier survivability in "system" and "soldier" terms as follows:

System. The characteristics of a system that can reduce fratricide, as well as reduce detectability of the soldier, prevent attack if detected, prevent damage if attacked, minimize medical injury if wounded or otherwise injured, and reduce physical and mental fatigue.[3]

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[2] U.S. Department of Defense Regulation, *Mandatory Procedures for Major Defense Acquisition Programs (MDAP) and Major Automated Information System (MAIS) Acquisition Programs (DOD 5000.2-R*), Washington, DC, 11 May 1999.

[3] U.S. Department of the Army. Manpower and Personnel Integration (MANPRINT) in the System Acquisition Process, AR 602-2, Washington, DC, 10 January 1995.

Soldier. Those characteristics of soldiers that enable them to withstand (or avoid) adverse military action or the effects of natural phenomena that would result in the loss of capability to continue effective performance of the prescribed mission.[3]

The key words in the survivability definition in DoD 5000.2-R are "to avoid or withstand." These are measures of a system's <u>susceptibility</u> and <u>vulnerability</u> to the hostile environment.

Susceptibility is defined as "the degree to which a weapon system is open to effective attack due to one or more inherent weakness. (Susceptibility is a function of operational tactics, counter-measures, probability of enemy fielding a threat, etc.). Susceptibility is considered a subset of survivability."[2] Susceptibility can be divided into three general categories of threat activity: (a) detecting, identifying, acquiring, and tracking; (b) launch or firing; and (c) munitions impact or detonation. Susceptibility of a weapon system is influenced by such features as the system design (e.g., signature and maneuverability), tactics used (e.g., terrain masking to avoid detection), and survivability equipment and weapons it carries (e.g., electronic countermeasures).

Vulnerability is defined as “the characteristic of a system that causes it to suffer a definite degradation (loss or reduction of capability to perform its designated mission) as a result of having been subjected to a certain (defined) level of effects in an unnatural (man-made) hostile environment. Vulnerability is considered a subset of survivability.”[2] Vulnerability is determined by the system's design and any features that reduce the amount and effects of damage when the system takes one or more hits.

SURVIVABILITY AS THREAT AVOIDANCE

Survivability is based primarily on avoidance, as shown in Figure I-2 (i.e., avoid being detected; if detected, avoid being acquired as a target; if acquired as a target, avoid being hit; if hit, avoid being damaged; if damaged, avoid being killed).

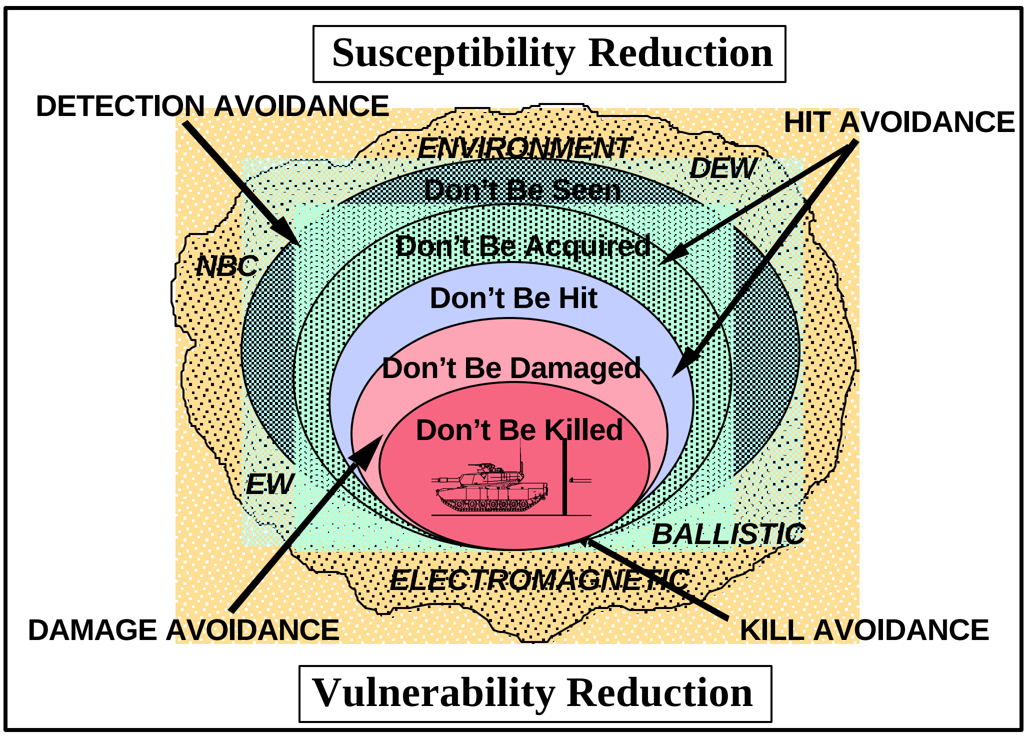


Figure I-2. Threat Avoidance Categories.

Mathematically, the probability (P) of survival can be expressed as follows:

P(Survivability) = 1 - {P(Detection) • P(Acquisition given Detection) • P(Hit given Acquisition) • P(Damage given Hit) • P(Kill given Damage)}.

This set of conditions has been fundamentally true since the beginning of warfare. What has changed over time is the probability of occurrence of each of the elements in a given set of circumstances. If any element of survivability (avoidance of detection, acquisition, hit, penetration, and kill) can be improved, then the overall probability of survival is increased.

SOLDIER SURVIVABILITY CHARACTERISTICS

The individual soldier continues to be the focus of the close fight. Soldiers as land and aircrew members are also central to the effective performance of all manned weapon systems.

Dramatic improvements in war-fighting capabilities will occur by improving/enhancing soldier survivability in two primary ways: (1) by designing a better soldier system for land and air operations and (2) by ensuring all weapon systems incorporate systems design characteristics to enhance soldier survivability. Soldier survivability characteristics are those which:

Reduce Detectability of the Soldier. Prevent the visual, acoustic, electromagnetic, infrared/ thermal, radar detection by the enemy of individual soldiers, mounted or dismounted. Detectability reduction could include the use of low-observable technology, smoke, training, and doctrine.

Prevent Attack on the Soldier, if Detected. Methods of preventing attack include using decoys and warning sensors for ballistic and NBC attacks and employing maximum effective ranges of friendly weapons outside the enemy's maximum effective range.

Prevent Bodily Damage, if Attacked. This component includes protecting the soldier from traditional insults such as bullets, shrapnel, blast, and thermal; and preventing damage from chemical agents, biological agents, nuclear, and laser, high-powered microwave and acoustic systems. Further, the soldier should be protected from natural phenomena such as temperature extremes or deep water. Measures for preventing bodily damage include armored compartments for mounted soldiers, fire suppression systems, ballistic protection jackets, nonflammable fabrics, chemical protection clothing, visors with tunable laser protection, and cold weather clothing.

Minimize Medical Injury, if Wounded. If a soldier is wounded, efforts must be made to prevent fatality or physical disabilities and evacuate the soldier quickly and efficiently to medical treatment facilities. Casualty reduction measures include first-aid packets, bodily function sensors connected to a vehicle, or personal computer/communications system, antidotes, trauma treatment at the squad/crew level, and escape hatches.

Reduce Fratricide. Reduce the unforeseen and unintentional death or injury of personnel resulting from the employment of friendly weapons and munitions. Soldier and other weapons systems should be designed with improved antifratricide systems such as identification of friend or foe (IFF) and situational awareness systems.

Reduce Physical and Mental Fatigue. Soldiers must receive proper sustenance and be equipped with the clothing and equipment that maintain physical capabilities and enhance mental alertness. In addition, vehicle, aircraft, and soldier systems must not increase physical stress on the soldier. Relevant measures include lightweight protective clothing, highly nutritious rations, on-board hygiene systems, reduced noise levels, crew comfort, chemical protective suits that breathe, and other efforts to reduce anxiety in combat (e.g., decision aid systems and sensor technologies that provide opportunities to sleep).

SURVIVABILITY DYNAMICS

Military historians have occasionally categorized battlefield technological developments in terms of the time it will take an adversary to devise a way to defeat it. While the amount of time necessary to overcome a technological innovation may vary, the message is nonetheless clear—nothing on the battlefield is invulnerable or stays that way for very long. As new technology is developed and refined, weapon lethality increases, but the same dynamic technology growth also produces the innovations necessary to increase system survivability, as illustrated in Figure I-3. As time moves on, technological complexity increases, while more lethal weapons and better defenses against them struggle for superiority. Cost also usually increases.

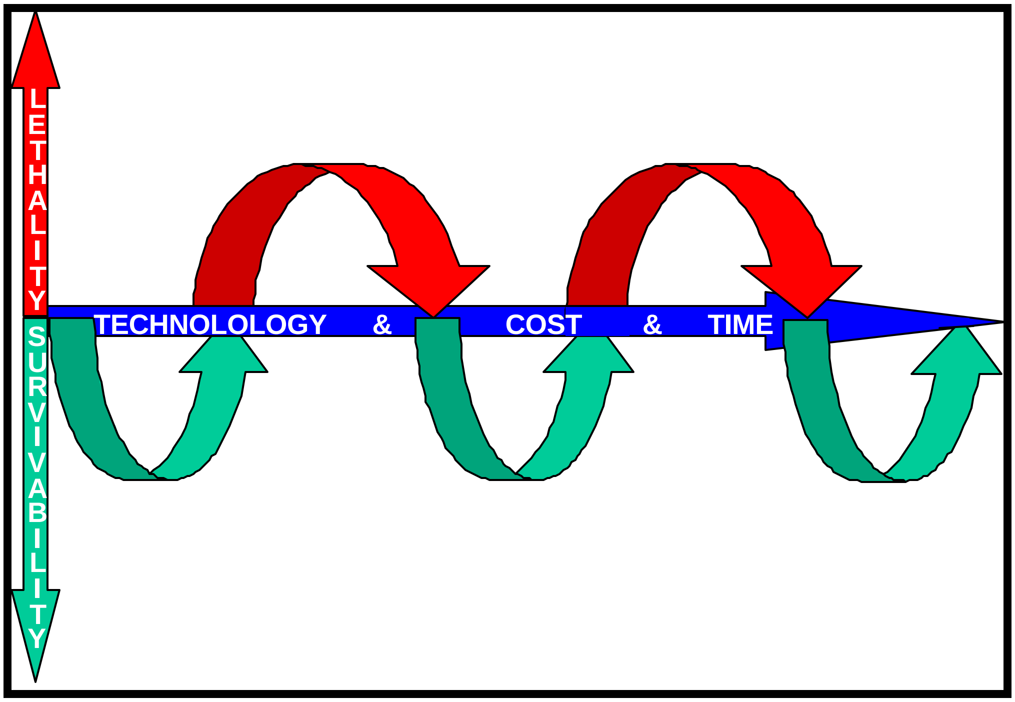


Figure I-3. Survivability Dynamics.

As advances in computer-aided system design, rapid prototyping, use of commercial-off-the-shelf (COTS) equipment, and streamlined acquisition procedures shorten new system development cycles, the tempo of the struggle between lethality and survivability is quickening. This technology cycle presents unique challenges to system designers, who must design a system today to be survivable on the battlefield tomorrow. Combat and materiel developers must remain continually alert to changes in the threat and environment forecasts as they take place throughout the life cycle of a system, not just during its development. All concerned must expect that whatever systems are designed, their survivability should be regarded more as a perishable commodity rather than a one-time capital investment.

SURVIVABILITY ANALYSIS

It is possible to reduce a weapon system's vulnerability to one or more specific threats but inadvertently increase the vulnerability to one or more other threats. Thus, it is essential that the effects of all threats on a system be examined in an integrated manner. It is also essential that survivability enhancement recommendations be analyzed and tested for effectiveness of their intended purpose and their compatibility with other applications. The Army's system survivability, lethality, and vulnerability (SLV) analysis process is a comprehensive, integrated process that determines if the plan for a new system, a modification to an existing system, or an Equipment Change Proposal (ECP) enhances survivability or reduces vulnerability or susceptibility. The Army's principal organization for performing this type of analysis is the Army Research Laboratory's Survivability/Lethality Analysis Directorate (ARL SLAD). More detailed information on this organization, its capabilities, and how to contact them are presented in Section II.

The survivability of a component, subsystem, or the entire system may change during the various phases of the system's life cycle. Some of these changes are a result of changes in the design, changes in the manufacturing techniques, or changes in the final materials. For example, the adverse effect of a long rod penetrator against an armored vehicle might be lessened with the addition of a particular spall liner. Doing this may lead to the assumption that the survivability of the armored vehicle has been improved. If, however, it turns out that the spall liner material emits a toxic substance or easily results in a catastrophic fire when penetrated by a shaped charge jet, the survivability of the armored vehicle may have been increased in one respect (i.e., long rod penetration) while inadvertently decreased in other respects. A properly conducted integrated survivability analysis would reveal the dilemma so that corrective action could be taken before an original enhancement was implemented. While a proposed survivability enhancement may appear very promising in theory, it is essential that qualified scientists and engineers perform a rigorous survivability analysis so that the overall survivability of the system can be determined based on the best information available. The process of performing a comprehensive SLV analysis is complex, detailed, and can extend over a period of many years. An overview of a general SLV analysis, with some of the steps and parameters that must be considered, is presented in Section II.

SURVIVABILITY IN RESEARCH, DEVELOPMENT, AND ACQUISITION

Research, development, and acquisition (RDA) survivability considerations are guided by DoD regulation 5000.2-R, which states that: "unless waived by the Milestone Decision Authority (MDA), mission-critical systems, regardless of acquisition category (ACAT), shall be survivable to the threat levels anticipated in their operating environment. System (to include the crew) survivability from all threats found in the various levels of conflict shall be considered and fully assessed as early as possible in the program, usually during Phase I."[2]

All acquisition programs are based on identified, documented, and validated mission needs resulting from ongoing assessments of current and projected capability. Validated mission needs may be satisfied by changes in doctrine or training or by materiel solutions. Mission needs requiring materiel solutions may be satisfied by a new operational capability, by improving existing capabilities, by exploiting opportunities to reduce costs or improve performance, or by enhancing system survivability and lethality. This is formalized by the preparation and approval of the Mission Need Statement (MNS).

If the mission need requires a materiel solution, the RDA cycle begins with the Concept Exploration (CE) phase. During this phase, the focus of the effort is to define and evaluate the feasibility of alternative concepts and to provide a basis for assessing the relative merits of these concepts at the next milestone decision point. The most promising concepts are defined in terms of initial broad objectives for cost, schedule, performance, opportunities for tradeoffs, and strategies for acquisition, and test and evaluation. During this phase, several survivability requirements should be addressed. First, a Systems Threat Assessment Report (STAR) is prepared which defines each threat to the system by category and likelihood. Then the initial survivability objectives are defined and validated, and the objective criteria are established. After this is accomplished, the critical survivability shortfalls are identified, and the research requirements are established. Finally, the survivability requirements are defined in quantitative and qualitative terms.

At each milestone, beginning with program initiation, thresholds and objectives initially expressed as measures of effectiveness or performance and minimum acceptable requirements for the proposed concept or system are documented by the user in an Operational Requirements Document (ORD). The ORD describes the overall mission area, the type of system proposed, and the anticipated operational and support concepts in sufficient detail for program and logistics support planning. The ORD also describes a special category of characteristics that tend to be design, cost, and risk drivers such as electronic countermeasures and survivability against conventional, initial nuclear weapons effects, and NBC contamination. During the Program Definition and Risk Reduction phase, the program is defined as one or more concepts. Design approaches and/or parallel technologies are pursued as warranted. Prototyping, demonstrations, and early operational assessments are considered and included as necessary to reduce risk. Cost, interoperability, and acquisition strategy alternatives are considered during this phase. The actions related to system survivability in this phase begin with identifying the critical survivability characteristics and issues requiring test and evaluation. Survivability and other characteristics are reflected in the Test and Evaluation Master Plan (TEMP). Key survivability objectives are identified and quantified for inclusion in the overall development baseline system specifications and Integrated Logistics Support (ILS) Plan. Tradeoffs are made (e.g., cost vs. weight), and system specifications are prepared for the Request for Proposal (RFP). DOD 5000.2-R requires that system (to include the crew) survivability from all threats found in the various levels of conflict shall be considered and fully assessed as early as possible in the program, usually during Phase I.

The objective of the Engineering & Manufacturing Development (EMD) phase is to transition the most promising design approaches into a stable, interoperable, producible, supportable, and cost-effective design; validate the manufacturing or production process; and demonstrate system capabilities through testing. Part of the testing during this phase is an assessment of how well the survivability objectives have been met. All survivability issues should be resolved during this phase. The key survivability objectives are included in the system and subsystem specifications, as well as in RFP and contracts. After EMD, a Milestone III Decision Review is conducted to determine if the program is ready to enter the Production, Fielding/Deployment, and Operational Support phase. Deficiencies noted during testing are resolved, and fixes are verified. The impact on the survivability of the system due to any modifications, engineering change proposals (ECPs), etc., must be ascertained before the system enters the force.

REDUCING RISK EARLY

While the importance of survivability throughout system development is generally recognized and accepted, in reality, survivability efforts are as much or even more beneficial when applied prior to the establishment of a “formal” system. The overall cost of a system is significantly reduced when survivability is “built-in” rather than "added-on," as indicated in Figure I-4. Considerable impact on the survivability of an eventual system can and should be effected during science and technology (S&T) developments, concept studies, and warfighting experimentation. A major Army initiative that can have a significant impact on survivability (as well as RDA) is the early insertion of the Army warfighting experiments (AWEs) for advanced technology demonstrations (ATDs) and advanced concept technology demonstrations (ACTDs), if survivability considerations are part of the AWE. Because 90% of RDA costs can be influenced by decisions made before Milestone II, it is imperative that we make the right decisions early. Risk reduction during the later phases (e.g., EMD) is much more expensive. Reducing risk early can be accomplished through various methods to include the aforementioned AWEs, ATDs, and ACTDs, as well as a greater use of modeling and simulation (M&S). M&S can include live simulations and field trials, constructive simulations, and distributed virtual simulations. The live simulations and field trials use "real soldiers" and "real units" in a tactically competitive environment. The constructive simulations and distributed virtual simulations can replicate the combined arms battlefield with increasing fidelity. The results of these simulations serve to speed up the development cycle by better determining the benefits and shortcomings of a system before the commitment of greater resources.

For the full benefit of survivability efforts to be realized, they must be aggressively pursued not only during system development, but also early in the considerations for any P3I program, system modifications such as ECPs, or purchases of COTS. It is essential that survivability be considered throughout the acquisition cycle.

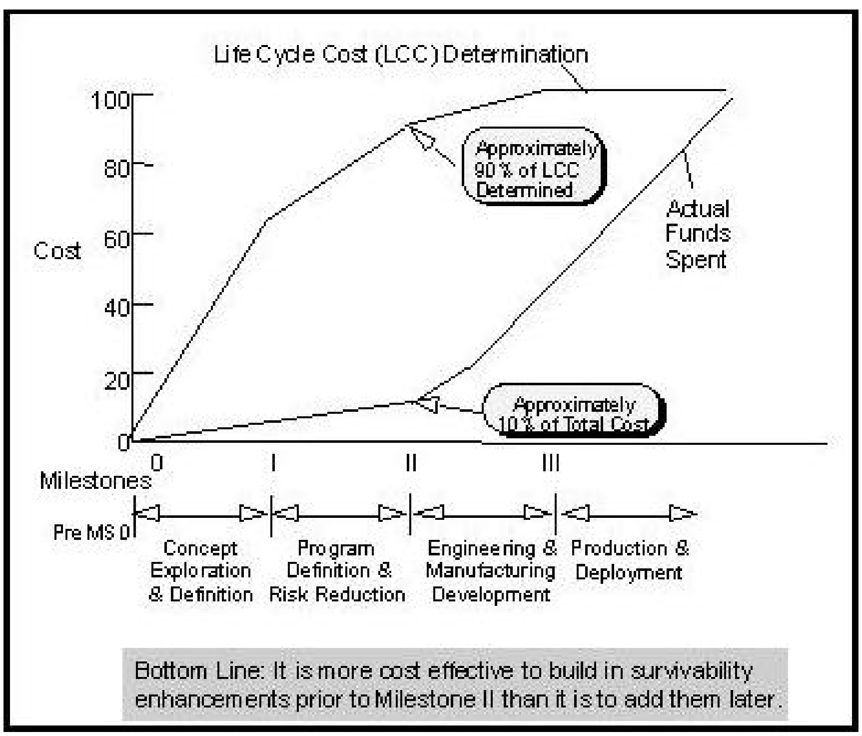


Figure I-4. Life-Cycle Cost.

SOLDIER SURVIVABILITY

The Army has recognized the need to consider the soldier in a manner befitting his importance as the ultimate battlefield system. The Army instituted the Soldier as a System (SAAS) concept to permit the combat potential of each soldier to be fully realized. The terms "soldier as a system" and “soldier system" do not imply that the Army perceives soldiers in impersonal terms (i.e., they are not machine-like). Rather, in establishing the Soldier System, the Army now gives the visibility and management to soldier programs that major weapons systems have had for years. Major weapons systems are characterized by integrated, centralized management and funding. Today's Army is doing the same for the individual soldier. Because the individual soldier continues to be the focus of the close fight, dramatic improvements in warfighting capabilities will occur as Soldier System survivability is enhanced. Some of the system design goals for soldier survivability include reducing fratricide, detectability, attack, bodily damage, medical injury, and physical and mental fatigue. Another survivability issue is the combat load weight carried by the dismounted warrior. The heavier the load, the slower the soldier moves, and the more fatigued he becomes. Both factors contribute to lower survivability. Soldier survivability also includes preventing those things that have an adverse impact on soldier health and performance. Nothing is more critical to improving the capability of the Army than improving the survivability of the individual soldier. A central focus on the survivability of the soldier provides RDA goals such as:

(a) acquiring materiel systems that fully integrate the soldier’s safety and survivability as a critical component of the system’s performance, lethality, and survivability;

(b) assuring that RDA of fratricide reduction technology fully considers soldier performance parameters rather than just materiel solutions;

(c) assuring crews can complete missions using NBC protective gear without the gear itself endangering their lives; and

(d) medical research for protection against threats for individual soldiers, crews, and units, as well as improvements in evacuation technology.

MAKING MAXIMUM USE OF INVESTMENTS

The Army must make full use of its previous investments by maintaining equipment currently in the force. This means that every effort must be made to improve capabilities through preplanned product improvements and other upgrade programs before acquiring new systems. In any case, survivability enhancements do not have to wait until the next generation of systems is fielded. Every effort should be made to develop solutions that can be applied with the least degradation of the Army's mission requirements and at the lowest cost.

LIVE-FIRE TESTING

Federal law and DoD regulations provide specific live-fire testing requirements during the acquisition process. Federal law[4] requires that a covered system may not proceed beyond low-rate initial production until realistic survivability testing of the system is completed.

[4] U.S. Code. *Major Systems and Munitions Programs: Survivability Testing and Lethality Testing Before Full-Scale Production*, Title 10, Section 2366, Washington, DC.

The term "realistic survivability testing" means, in the case of a covered system (or a covered product improvement program for a covered system), testing for vulnerability of the system in combat by firing munitions likely to be encountered in combat (or munitions with a capability similar to such munitions) at the system configured for combat, with the primary emphasis on testing vulnerability with respect to potential user casualties, and, taking into equal consideration, the susceptibility to attack and combat performance of the system. The term configured for combat refers to a weapon system, platform, or vehicle loaded or equipped with all dangerous materials (including all flammable and explosives) that would normally be on board in combat. Waivers or alternative testing may be approved under certain conditions as prescribed in DoD 5000.2-R. However, a waiver of requirements for realistic survivability testing does not eliminate the need for survivability testing of components, subsystems, and subassemblies.

The first system to undergo live-fire testing was the Bradley Fighting Vehicle System (BFVS) in 1987. The BFVS had 150 offline tests and 123 full-up live-fire shots. The Army learned much from these live-fire tests. In particular, the contribution of the behind armor debris phenomenon in causing casualties and damage to systems and equipment in the vehicle interior was revealed. This led to the development of spall liners for the BFVS and also the M113 armored personnel carrier families of vehicles, which significantly improved the overall survivability of these systems. The Army test, evaluation, and analysis communities have become very adept at maximizing the information gained from live-fire testing while reducing the number and cost of these tests. Over time, greater confidence has been developed in computer simulations and modeling of the various mechanisms of attack (lethality). Currently, the emphasis is on component/subsystem and nondestructive testing to reduce the number of very expensive full-up live-fire tests.

SURVIVABILITY IMPROVEMENT LATER IN THE LIFE CYCLE

Most major Army weapons systems tend to have very long life cycles. It is not uncommon for them to last for several decades. Several factors can contribute to this longevity, such as cost and robustness of the original design. The M551 Sheridan saw three decades of active duty service, despite less than universal satisfaction with its performance and, in particular, its survivability characteristics. The M113 family of vehicles (FOV) is still in service after more than four decades since its initial fielding. Today’s M113 FOV is an example of how the survivability of a major system can improve over time. The original version of the M113 was gasoline fueled and was subject to catastrophic loss from fuel tank explosions. Conversion to a diesel engine was a considerable improvement. Extensive survivability analysis and live-fire testing led to the introduction of spall liners and external armored fuel cells, further improving the system’s survivability. Even greater survivability enhancement was achieved with the development of armor tiles for the M113.

The survivability of major weapons systems with respect to evolving threats must be periodically analyzed and reviewed in order to determine when survivability upgrades should be undertaken and what form they should take. Preplanned product improvements (P3I) and block improvement programs are two means. Other opportunities for improving survivability will occur during recapitalization events, such as extended service programs, depot overhauls, and deliberate technology insertion. Development and exploitation of the most promising survivability technologies with a view toward horizontal insertion across multiple platforms and designing with the necessity for changing and/or improving the system’s survivability throughout its life cycle offer the opportunity to mitigate the expense while still improving survivability.

TRENDS IN SURVIVABILITY

The current emphasis on mobility and deployability is driving a search for more efficient protection, particularly from ballistic threats. In this case, efficiency relates to the mass (weight) or volume of armor, or component redundancy, required to provide a given level of protection. As the Army transitions to a rapidly deployable combat brigade as part of a full-spectrum force, a number of approaches and platforms will be investigated. These approaches will likely range from the application of more efficient materials, such as titanium or composites, to explosive reactive armor. Nontraditional approaches, such as electronic warfare and active protection, where threats are deflected while they are still inbound, are also under investigation.

While there does not appear to be a likely peer threat to emerge in the near- to mid-term, U.S. systems are likely to be attacked at their most vulnerable points by an adversary’s best weapons. Asymmetric threats are an increasing area of concern. Therefore, increased emphasis on dealing with such threats as weapons of mass destruction and, in particular, biological and chemical threats is appropriate. As a matter of both efficiency and cost effectiveness, U.S. defenses against nuclear, biological, and chemical (NBC) threats will, for the most part, be dealt with in the joint arena in the future. There are many potential improvements in the technology base, but NBC defense will remain a very challenging area for the foreseeable future.

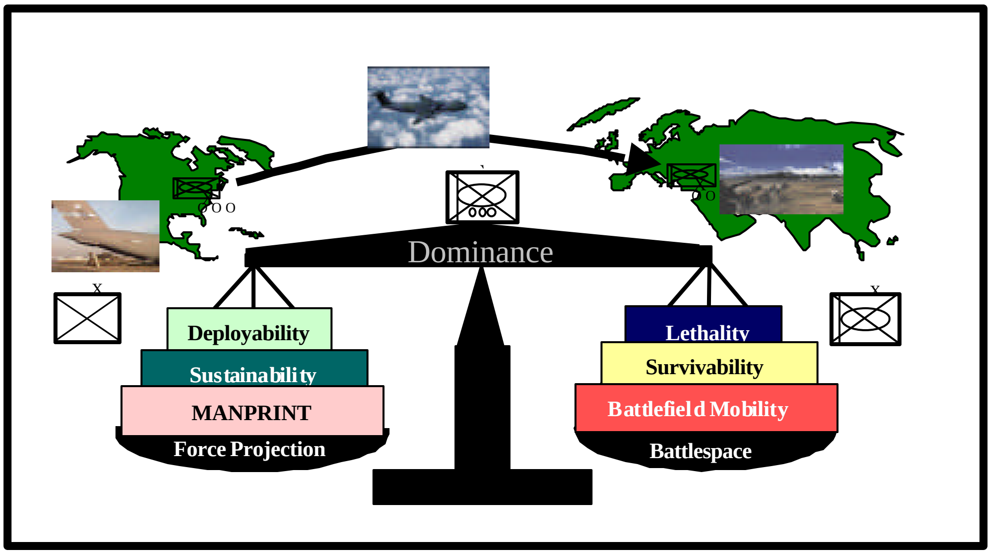
Information dominance presents both opportunities and new susceptibilities and vulnerabilities. The U.S. Army’s digitization effort entails equipping the warfighter with a digital data generation and processing capability and access to a seamless digital data communications network. This effort entails eliminating existing information stovepipes by integrating, both horizontally and vertically, those communications and information systems that support the warfighter. While this is how to get to information dominance, it also presents new susceptibilities and potential vulnerabilities. Where before an attack on an individual combat vehicle presented a threat only to that system, in the digitized force, an information attack on any vehicle in the network may pose a threat to an entire network, with the vehicle serving as a network entry point. Also, the reliance on commercial off-the-shelf (COTS) hardware and software in the digitization effort presents challenges to the security of the digitized force. Reliance on COTS technologies increases the likelihood that adversaries and potential adversaries will have access to information technologies similar to those the U.S. possesses. Faced with so many potential forms of attack and means of access to the Army Tactical Internet, a new approach to survivability may be required. This may be based on networks that are resilient and adaptive rather than undetectable or unassailable.

CONCLUSION

The Army has begun to transition into a force that will satisfy current needs to be more strategically responsive and dominant in meeting requirements for small scale contingencies without compromising its major theater war capability. To achieve this goal, the Army will develop a capability, using available systems and technical insertions, to provide an interim solution. The brigade combat team (BCT) optimizes the tenets of this operational concept and organizational design by achieving the most effective balance of force projection and battlespace dominance, as shown in Figure I-5.* Investments will be in today's off-the-shelf technology to stimulate the development of doctrine, organizational design, and leader training even as the search begins for new technologies for the objective force.

One key to achieving this vision is survivability. The Army intends will derive the technology that provides maximum protection to its forces at the individual soldier level whether, that soldier is dismounted or mounted. The combined goals are to dominate the expanded battlespace, and at the same time, protect the force.

Survivability analysis plays an important role in this vision. At the system level, it provides combat developers with an understanding of the impact various requirements have on a design's survivability. For materiel developers, it assists in making the cost/effectiveness tradeoffs to achieve the system's requirements. Later in a system's life, survivability analysis provides the data needed to assess the impact of changes in threat and what can or must be done about them. The ultimate value of survivability analysis is to quantify information for leaders and decision makers so that risks to soldiers and weapon systems can be understood and decisions can be made effectively.



*Extracted from briefing titled "The Army Vision – A TRADOC Perspective" Brigade Industry Day, 1 Dec 99.

Figure I-5. Achieving Force Effectiveness.

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SECTION II
THE U.S. ARMY RESEARCH LABORATORY (ARL) SURVIVABILITY/LETHALITY ANALYSIS DIRECTORATE (SLAD)

GENERAL.

SLAD is the U.S. Army focal point for technical advice and consultation on vulnerability and lethality analysis and integrated technical analysis of the survivability of all major Army systems throughout their life cycles. SLAD quantifies, through investigations, simulations, lab/field experiments, and analyses, the survivability, lethality and vulnerability (SLV) of all major Army systems against the full spectrum of battlefield threats throughout the system's life cycle. SLAD also plays an active role in materiel acquisition programs, including soldier survivability assessments, and designs, procures, operates, and maintains the requisite facilities and tools to support the Army's SLV analysis program requirements.

SLAD (and its predecessor organizations) has a long history of survivability and lethality analysis that predates the formation of the organization in 1992. Drawing from diverse activities involved in survivability and lethality analysis, SLAD has consolidated the necessary tools, techniques, and methodologies necessary for analysis of systems and soldiers against the full spectrum of battlefield threats and conditions, including conventional ballistic, electronic warfare, directed energy, information warfare, NBC, and the effects of electromagnetic environments and atmospheric conditions.

HISTORY.

SLAD was created in 1992 as part of the formation of ARL. It was formed from previously separate U.S. Army Laboratory Command components that had led the Army's SLV research and analysis. SLAD has two divisions. The Ballistics and NBC Division (BND) is composed of the former Vulnerability/Lethality Division of the U.S. Army Ballistic Research Laboratory (BRL), a portion of the Nuclear Survivability organization from the Harry Diamond Laboratory, and the Chemical/Biological and Assistance elements from the Chemical and Biological Defense Command (CBDCOM). The Information and Electronic Protection Division (IEPD) was created from the former Vulnerability Assessment Laboratory, a portion of the Atmospheric Sciences Laboratory, and the smoke analysis element from CBDCOM.

Before the inception of SLAD as a directorate within ARL, all of the previously mentioned organizations were responsible for discipline-specific survivability and lethality issues of Army systems. These activities were not well coordinated, and they competed for time and resources. Additionally, results were presented in incompatible formats and at different times in the acquisition process. This process contributed to making trade-off decisions difficult or impossible. Survivability issues are interdependent. They must be integrated technically to ensure that improving survivability from one threat does not decrease survivability in other areas.

The Army's leadership realized that comprehensive analysis capabilities were important. However, it would be unaffordable to have comprehensive SLV at each of the Army's Research Development and Experimentation Commands. Therefore, the capabilities were consolidated into one activity. The activity (SLAD) was placed in ARL to promote synergy with the technology based activities of ARL. Although SLAD is a relatively new organization, it also has decades worth of experience and expertise in all of the critical and highly specialized areas relevant to survivability and lethality analysis.

MISSION AND MAJOR FUNCTIONS.

SLAD's mission (portrayed in Figure II-1) is to provide SLV analysis and evaluation support over the entire life cycle of major Army systems and help acquire systems that will survive and/or be highly lethal in all environments against the full spectrum of battlefield threats.

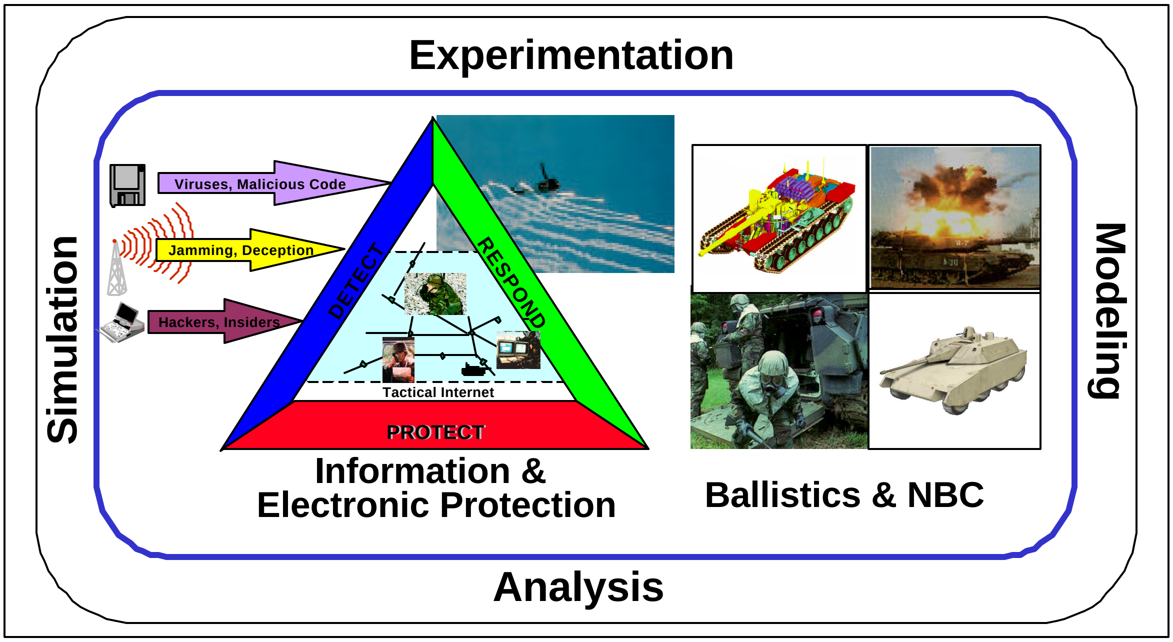

Figure II-1. SLAD's Mission and Major Functions.

SLAD's major functions are as follows:

- Conduct investigations, experiments, simulations, and analyses to quantify the SLV of U.S. Army and selected foreign weapon systems and to provide independent, well-documented technical judgments on complex SLV issues.

- Provide advice/consultation on SLV issues to Department of the Army Headquarters, program executive officers/project managers, evaluators, combat developers, battle labs, intelligence activities, and other Department of the Army and Department of Defense activities.

- Perform special studies and investigations in order to reduce vulnerabilities and enhance survivability/lethality. Work with technology based activities to find new SLV technologies and applications. Make recommendations regarding tactics, techniques, or designs to reduce the vulnerability and enhance the survivability and lethality of U.S. Army materiel.

- Develop tools, techniques, and methodologies for conducting and improving SLV analysis.

ORGANIZATION AND LOCATIONS.

SLAD is one of seven directorates within ARL. As shown in Figure II-2, SLAD is organized into two divisions. SLAD's Ballistics & NBC Division is located at Aberdeen Proving Ground (APG), MD. The Information and Electronic Protection Division is located at APG , MD, White Sands Missile Range, NM, and Fort Monmouth, NJ.

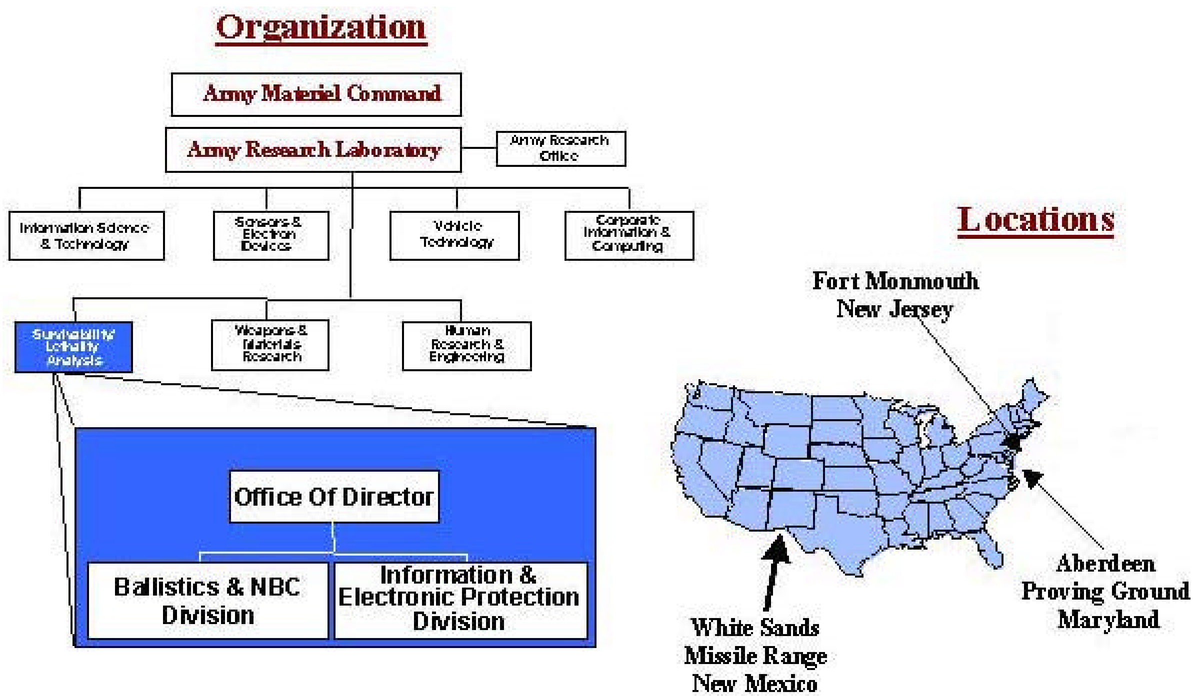

Figure II-2. SLAD Organization and Locations

SLAD SLV ANALYSIS CAPABILITIES.

SLAD’s analysis activities are based on science and engineering rather than operations research/systems analysis. They include theoretical analysis, modeling and simulation, physical experimentation, and data collection, reduction, and analysis. SLAD’s analysis capabilities include system survivability/lethality, ballistic vulnerability, nuclear/biological/chemical survivability, atmospheric/obscurants, electronic warfare, and information warfare.

SLAD’s tools, techniques, and methodologies available to analyze survivability and lethality include elements that apply to all threats. A representative sample is illustrated in Figure II-3.

SLV ANALYSIS PROCESS.

Figure II-4 depicts a general SLV analysis process with some elements or considerations of the process. The identification of a system’s needs to accomplish a given mission begins with a mission need statement (MNS). Establishing the specific survivability requirements for a system starts with defining the mission that the system must accomplish, coupled with the expected combat scenario(s) for that system. The mission definition sets the required maneuvers, speeds, operational concepts, tactics, and measures of performance throughout the entire mission.

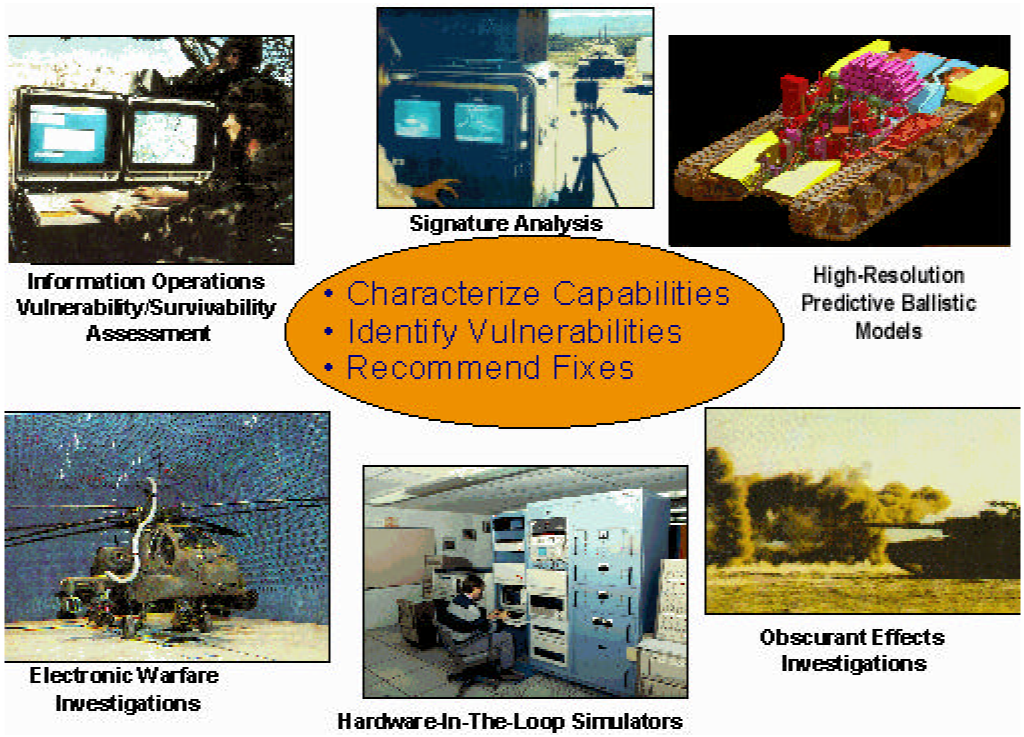

Figure II-3. SLAD Analysis Capabilities.

A threat analysis includes expected combat scenarios, the threat system characteristics and capabilities that might be encountered, the environment for the various threats (conventional ballistic, electronic warfare, directed energy, nuclear effects, and the effects of nuclear, chemical and biological contamination), the electromagnetic environment, and atmospherics. An estimate of future threats to the system is also required so that the ability to withstand those projected threats can be incorporated into the initial design or considered as future improvements. The five steps of the process are threat analysis, survivability requirements, system design and description, susceptibility, and lethality/vulnerability analysis will be discussed in separate paragraphs, which might give the impression that they are separate and independent events. They are, in fact, very closely related and interdependent.

Using information from the system/mission definition and the threat analysis, the user community develops the Operational Requirements Document (ORD), which contains survivability requirements, usually in very general terms. As the system concept becomes better defined and survivability issues and recommendations are provided, survivability requirements become an integral part of the acquisition documents and system specifications.

The system design/description includes an understanding of how the system is to function as well as the electrical, mechanical, and component layout. The functional description helps identify which components and subsystems are critical to the operation of the system and estimates the reduction in the capabilities of the system if any of the components and subsystems are degraded or permanently damaged. The physical properties of the system are also analyzed to include the resistance of the materials to the various threats.

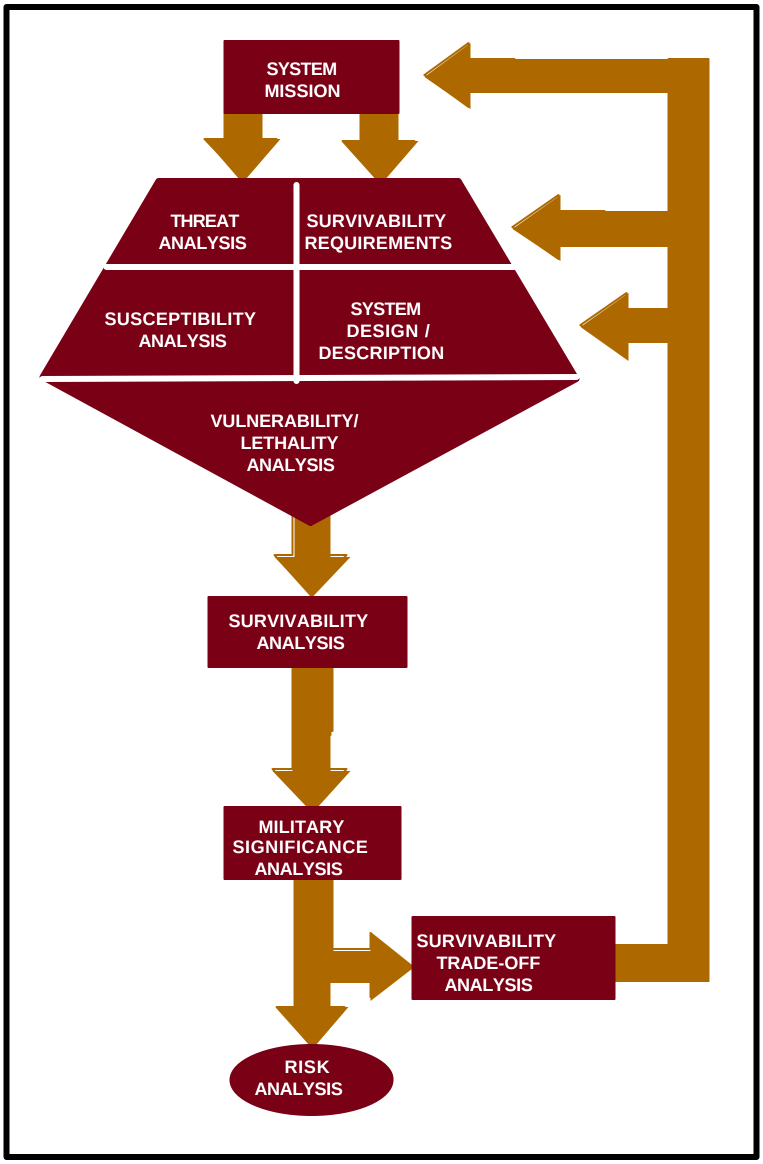

Figure II-4. Survivability Analysis Process.

Some aspects of a susceptibility analysis include target detection, acquisition, and identification (which relate to target signatures); tracking capabilities; jamming or other countermeasures that could affect tracking or lock-on; interceptibility of the system; and inherent weaknesses (i.e., weaknesses of a system regardless of whether or not that "threat" is a part of the current operational environment) of the system. A susceptibility analysis considers the sequence of events and elements in an encounter between the threat(s) and the system being attacked to the point where the threat is about to attempt to damage the system.

The degree to which the threat can damage the system and the resulting effects on the system are covered in a vulnerability/lethality analysis. A vulnerability/lethality analysis is two efforts, with one being the converse of the other. In a vulnerability analysis, the focus is on the effects of a threat system that might reduce the ability of a friendly system to complete its mission. A lethality analysis focuses on a friendly system that might reduce the ability of a threat system to complete its mission. Part of the vulnerability analysis determines if, and to what extent, a potentially destructive matter (a bullet or fragment, electrons from a jammer or high-power directed energy device, or a chemical/biological agent) can damage the system that is attacked. For chemical and biological agents, penetration into a system is not necessary to adversely affect the system. Once inside the system, effects of the threat on components, subsystems, and the total system must be determined from a physical and functional standpoint. The vulnerability analysis examines the criticality of each component and the effect of any degradation of a component to the overall system and determines the degraded condition or remaining capabilities of the system after it is attacked. The basic data to conduct the analysis can be generated from a variety of sources, to include computer models, laboratory, or hardware-in-the-loop investigations, or field experiments.

A survivability analysis uses information from a vulnerability analysis to assess the battle damage of components and the entire system. Also essential in conducting a survivability analysis are the times required to repair or replace damaged parts, the spare parts availability, and the logistics support provided to that system. Survivability deficiencies must be determined not only on an individual system basis, but on a more global perspective as well.

No system can be made invulnerable to all threats. When survivability deficiencies are identified, a military significance analysis is conducted to determine whether the survivability deficiencies are mission critical. If the deficiencies are mission critical, a trade-off analysis may be recommended to see if the deficiencies can be rectified by changing doctrine or tactics, initiating new training, introducing survivability enhancements, redesigning the basic system, or developing an entirely new system. Effectiveness of the various alternatives are analyzed. In other cases, where the cost to correct the survivability deficiency is unacceptably high with respect to the level of operational effectiveness gained, the Army may decide to accept the deficiencies. The ultimate value of SLV analysis is to provide the Army's decision makers with quantified technical information so that risks to soldiers and weapons systems can be understood and effectively managed.

HOW TO CONTACT SLAD.

SLAD is aligned within five mission areas. They include Aviation, Air and Space Missile Defense, C4I/Intelligence and Electronic Warfare, Ground, and Munition Systems. Within each of these five mission areas, SLAD has appointed a manager who is responsible for assuring that appropriate attention is focused on all of the appropriate SLV issues across all threat areas that may pertain to a particular system. This person, the SLAD Mission Area Manager (MAM) also serves as the initial point of contact for questions that may arise regarding a system and, in particular, serves as an initial entry point into SLAD for new customers or work. A comprehensive list of SLAD points of contact including the MAMs, as well as other key personnel, with phone numbers, email, and regular correspondence addresses, is available at the following website:

http://www-slad.arl.mil

The website also contains a great deal of other information about SLV and SLAD. You may also contact SLAD by calling the office of the Director, SLAD, at DSN: 298-6323 or Commercial: (410) 278-6323.